POTENTIAL CHANGES IN HYDROPOWER PRODUCTION FROM GLOBAL CLIMATE CHANGE IN CALIFORNIA AND THE WESTERN UNITED STATES

California Energy Commission

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Energy Commission Interests in Hydro and Climate Change

- *2003 Energy Report* Identified Climate Change Impacts to Water Supplies, Hydropower Production and the Environment as Major Issues for California
- Climate Change is Policy Area of Interest for Schwarzenegger Administration
- Energy Commission Sponsoring Climate Change Research through Public Interest Energy Research Program

Why The Energy Commission Developed This Paper

- Hydropower is Critical Element of State's Resource Mix
- Most Climate Change Studies Investigate Hydrology and Weather, but not Hydropower Production
- No Other Agency or Institution Has Examined at State-Level Scale
- Previous Study Looked at 6,000 MW of Low Elevation Hydro – Not Representative of Calif.

Report Purpose

- Identify Potential For Changes in Hydropower Production from Climate Change
- Assess the Literature to Identify Topical Studies
- Identify Key Variables and Issues for Further Study
- Conduct Quantitative Assessments as Data Allow
- Survey Hydro Producers and Planning Agencies
  - Who is doing What on the Issue?
- Recommendations for Next Research Phases

Report Structure

- Hydropower Infrastructure & Production in California, Pacific NW and Colorado
- Review of Climate Change Studies
- Climate Change Scenarios for California
- Effects on Key California Watersheds
- Incorporating Climate Change in Hydro Operations and Planning
- Effects on Coastal Power Plants

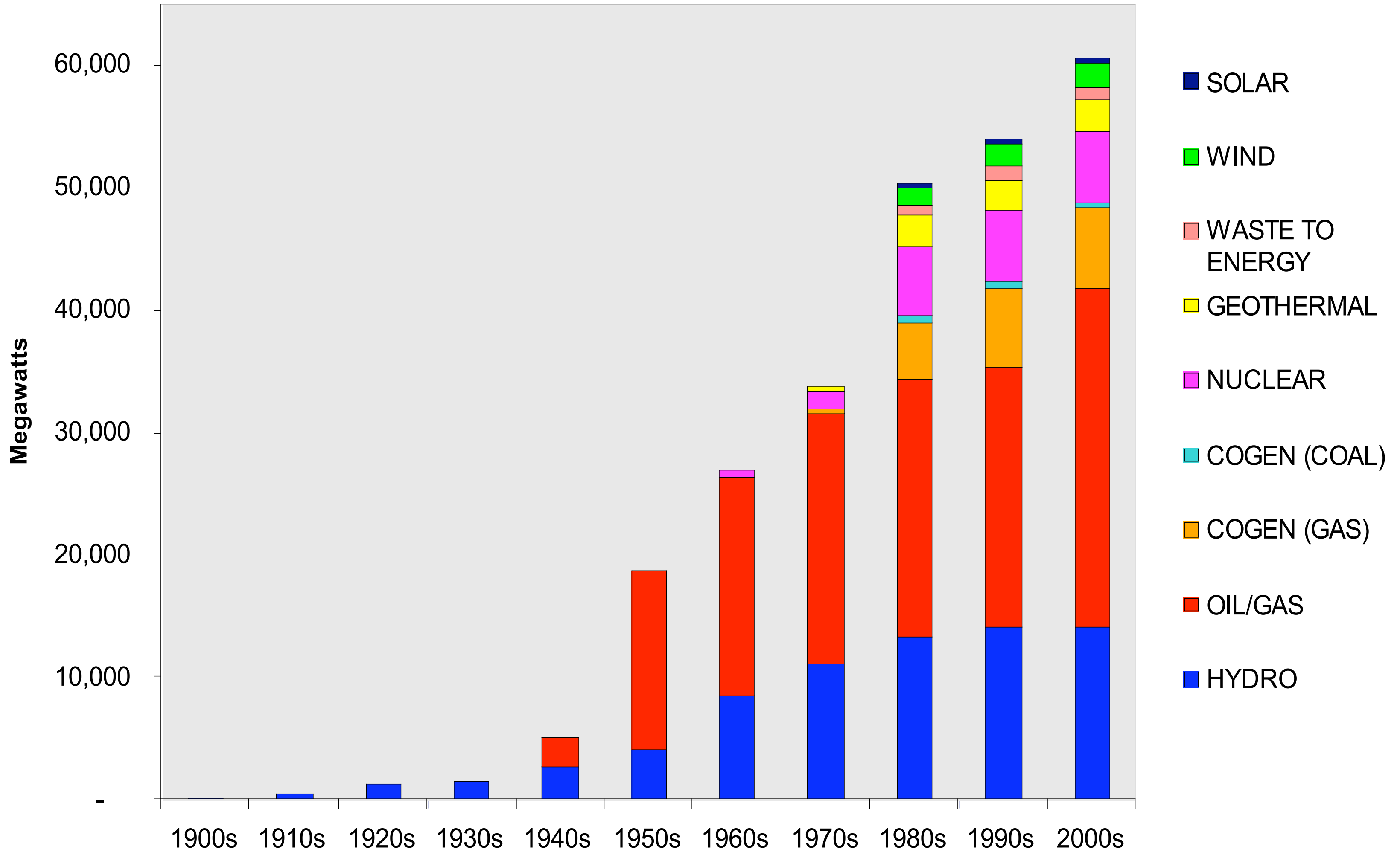
Hydropower Production

- California has 14,000 MW Capacity
  - Produces about 15% of energy supplies, 37,000 GWh in average year, but ranges from 9% to 30% depending on water year.
  - Summer Peaking Reserve Capacity important to meeting peak summer demand
- Pacific NW / Columbia Basin has 25,000 MW Capacity
  - Produces 140,000 GWh on average
  - Summer imports average 4,000 – 7,000 MW
- Colorado River has 3,600 MW
  - Produces 8,500 GWh on average
  - California’s Entitlements = 626 MW

Hydro's Role in Resource Adequacy

- Very low cost and flexible energy resource
- Important in meeting summer peak demands
  - 2005 forecast from 57,000 MW to 61,000 MW
- Summer Peaking Reserve Most Important from Resource Adequacy Perspective
- California Energy Infrastructure Developed Around Initial Hydro Development and Production Variability

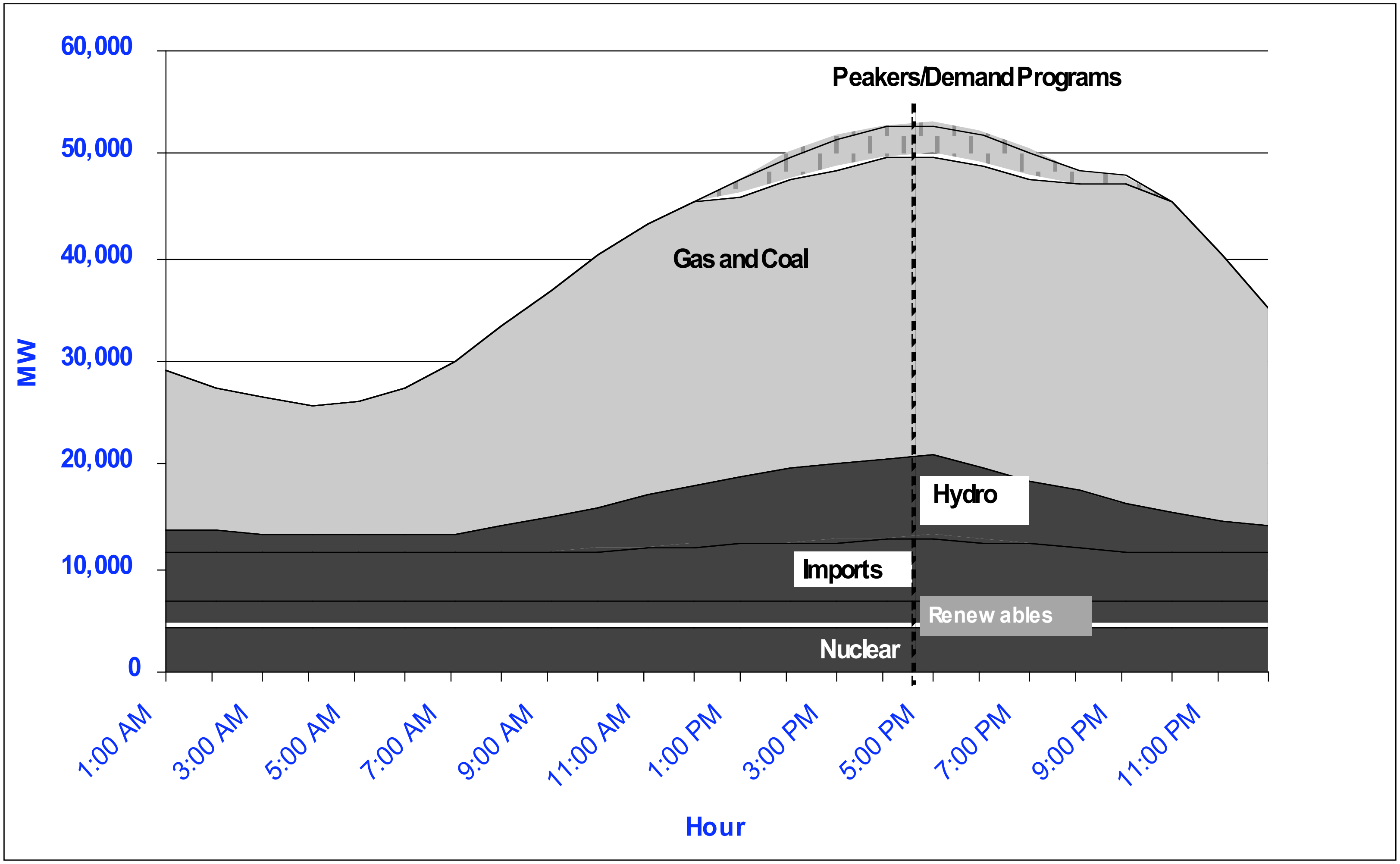
Cumulative Generating Capacity in California by Decade and by Fuel/Technology Type



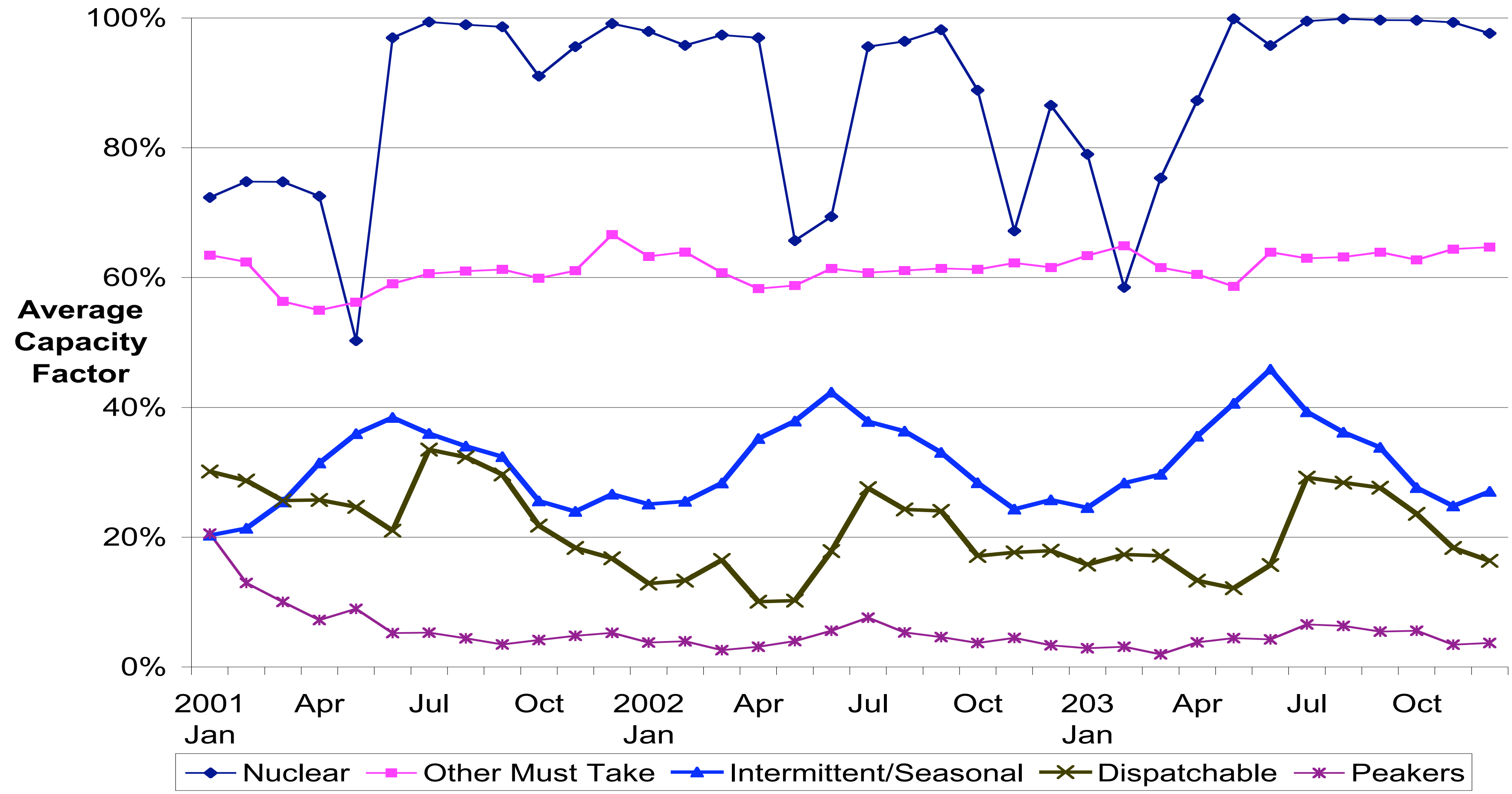
Perspective on Hydro's Role in Meeting Resource Adequacy

- Variable Resource with High Derate
  - 8,500 MW dependable capacity for Supply-Demand Balance Assessments
- Production Peaks During Spring Run-Off
  - Not a high demand period
- Fixed Resource with Limited Expansion Potential
  - Demand and generation capacity will continue to grow
- Gas-Fired Boilers, Combined Cycles and Peakers Provide Bulk of Load Following and Peak Energy

Electricity Supply Profile for a Typical Hot Summer Day



2001 to 2003 California Generation Average Capacity Factors



Key Issues and Variables in Analysis

- Ownership and Project Purpose
- Type of Hydro Project
  - Pumped Storage, Dispatchable, Run of River
- Elevation of Key Reservoirs and Powerhouses
- Ratio of Snow to Rain
- Changes in Freezing Line
- Ratio of Reservoir Capacity to Total Unimpaired Run-Off, by Watershed
- Shifts in Production Evaluated in Context of Existing Variance
- Shifts in Production During Year May Be More Important Than Total Annual Changes in Production
- Production Changes May Not Be Evenly Distributed Among Utilities

Hydropower Facilities in California

Owner Type	Owner	Capacity (MW)	Primary purpose
Investor-Owned Utilities	• PG&E	3,896	Power generation
	• SCE	1,163	Power generation
Water Projects	• Central Valley Project (USBR)	2,355	Water supply, flood control
	• State Water Project (DWR)	1,520	Water supply, flood control
Municipal Utilities	• Los Angeles DWP	1,761	Water supply, power generation
	• Sacramento MUD	688	Power generation, recreation
	• San Francisco PUC	385	Power generation
	• Other Municipal Utilities	513	Water supply
Water Districts	multiple	921	Water supply
Irrigation Districts	multiple	704	Water supply
Others	multiple	210	

Hydropower Operations

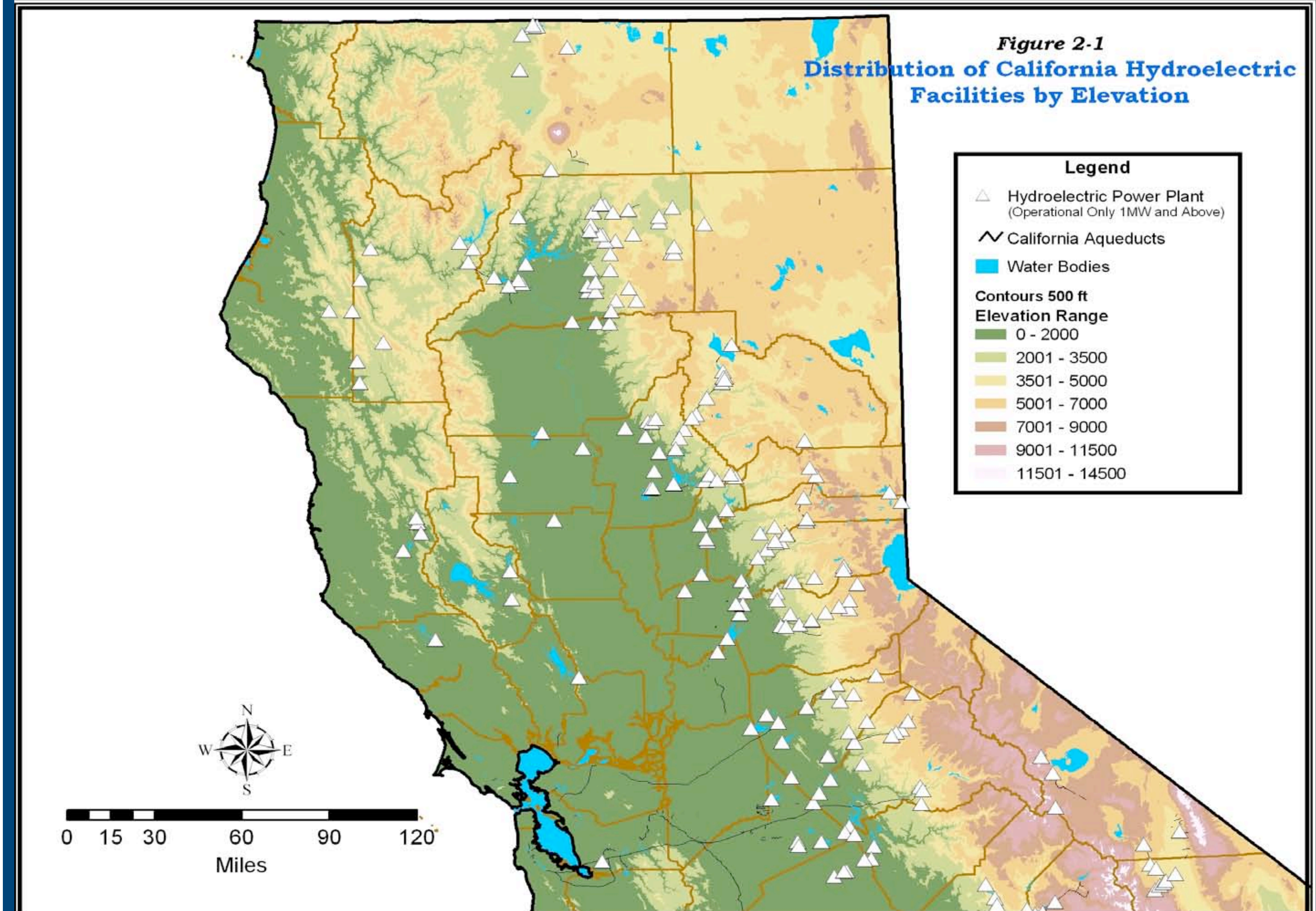
- Use a Function of Elevation
  - Higher: primarily power production (IOUs)
  - Foothills: mixed purposes (PUDs, IOUs)
  - Valley floors: water supply/flood control (Water Projects, PUDs)
- Facilities Designed for Current Hydrology
- Rely on Snowmelt Timing and Patterns
- PUDs with higher proportion of resources than IOUs

Hydro Capacity and Production by Selected Watersheds

Watershed	Hydro Capacity (MW)	Hydro Production (GWh)
American River	1,158	2,771
Feather River	1,661	5,533
Kings River	1,609	1,483
Sacramento – Pit River	1,506	5,779
San Joaquin River	1,089	4,076
Stanislaus River	724	1,938

Figure 2-1

Distribution of California Hydroelectric Facilities by Elevation



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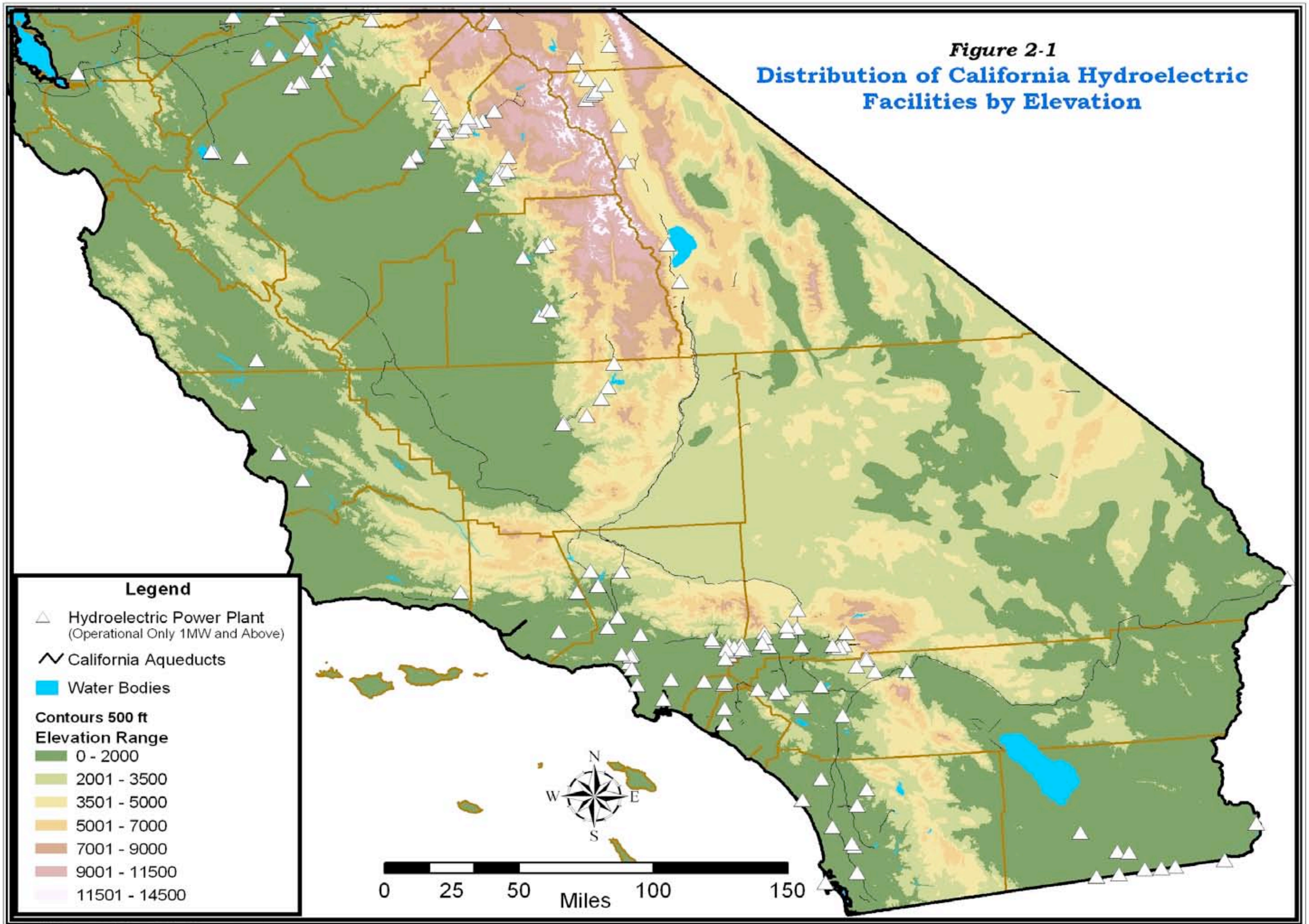


Climate Change Studies

- Large Number of Studies Specific to California
- PIER Sponsorship of Key Studies
- General Circulation Models Used to Depict Changes
  - Models Continuing to Evolve
- Most Studies Use Extreme Ends of Scenario Spectrum in Order to Bracket Effects

Comparability of Studies is Limited

- Greenhouse Gas Emissions Scenarios Vary
- Different GCMs are Used
- Scale of the Model can be Global, Regional, Local
- Purposes of Study Vary
- Time Periods Differ
- Geographic Areas of Study Differ

Climate Change Effects on Hydrologic Parameters

- Precipitation Changes Vary Widely; No Clear Relationship between Precipitation and Temperature
- Continuation of Current Warming Trend will:
  - Increase rain to snow ratio
  - Delay onset of snowfall season
  - Shorten overall snowfall season
  - Accelerate rate of spring snowmelt
  - Yield more rapid and earlier runoff; less summer runoff
- Changes Less Significant at Higher Elevations

Observed Changes in Hydrologic Parameters

- PG&E Evaluations of Its 3,896 MW system show:
  - Snowmelt induced runoff decreased over last 50 years
  - Decreasing trend in low elevation snowpack
  - Pit-McCloud Rivers, while at lower elevations, benefit from porous soils
  - Feather River more reliant on snowmelt; high runoff could cause system shutdown, water diversions
- PG&E's System Designed for Large Wetness Variance

Studies on Changes in Hydropower Production

- PIER Study Using Calvin Model Showed Significant Changes in 2100
  - Hydropower decreases using dry GCM
  - Hydro increases in winter and decreases in summer using wetter GCM
- Sacramento-San Joaquin Study Shows Decline (up to 11%) in Production using Dry GCM
- Changes Not In Sync with Demand Changes (↓ in winter, ↑ in summer)

Pacific Northwest/Columbia River Basin Studies

- Climate Change Studies Show Same Changes to Hydrologic Parameters
- Using dry GCM, Hydropower Production Drops But Less Than 10%
- Summer Surplus Capacity May Fall - Less Power to CA and Competition For Replacements
- PNW May Need to Plan For Both Winter and Summer Peaks

Colorado River Basin Studies

- Climate Change Studies Show Same Changes to Hydrologic Parameters
- Using Dry GCM, Snowpack Decreases 30%
- Runoff Decreases by 15% with Major Effects to Hydro/Water System
- Hydropower Production Declines by 50%

Range of Climate Scenarios

- Analyses Identify Range of Possibilities, not Forecasts or Predictions
- No Probabilities can be Assigned
- Two Scenarios Bound Year 2100 Cases

  - Very wet HadCM2 model: runoff increases by 76%

  - Very dry PCM model: runoff decreases by 25%

Value of Looking at Scenario Range

- Use Results to Choose Among Different Resource-Planning Options
- Reexamine Priorities and Coordinate Policies

  - flood control/hydropower, water supply, environmental protection
- Use Results in Future to Fine-Tune Changes in Runoff Timing and Variations in Elevation

Additional Factors Affecting Hydropower

- Generation Capacity: Relative Importance to Grid
- Reservoir Size: Ability to Shift Flows to Summer Peak
- Flow Relative to Reservoir Size: Ability to Accommodate Earlier Runoff and Variations
- Elevation: Relation to Snowline and Reservoir Capacity

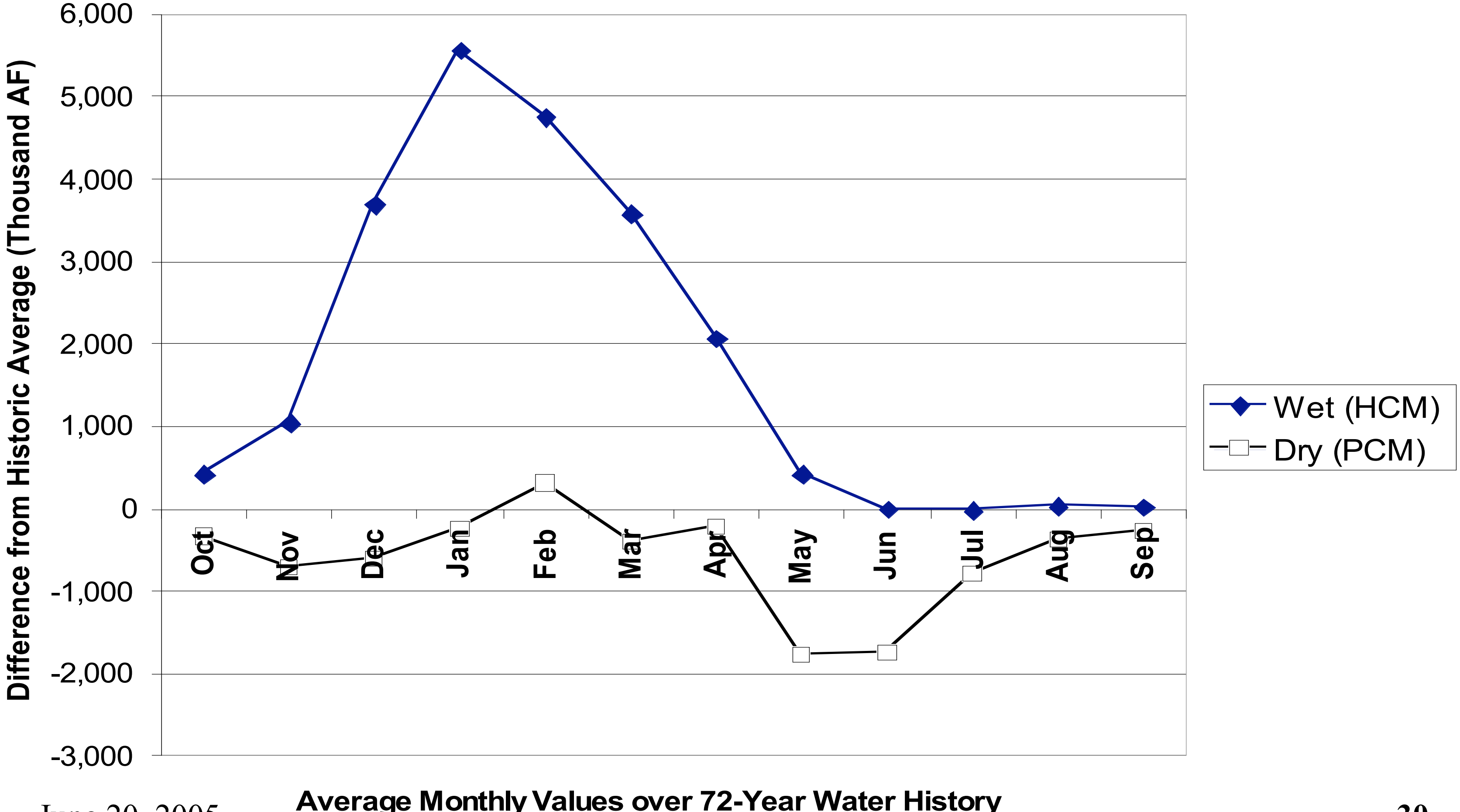
Implications of Changed Runoff for Hydropower

- Snowpack acts as a large "reservoir" for spring and summer releases.
- A decreased snowpack going into the spring would mean that the "reservoir" of snow that the state has counted on to provide water for hydropower during the summer could be depleted earlier.
- Increased winter flows could increase flood protection requirements, which could reduce storage for summer use. Particularly true for dry PCM scenario.
- With reservoir capacity well below the majority of generating capacity less runoff will be captured for summer peaking power demand.

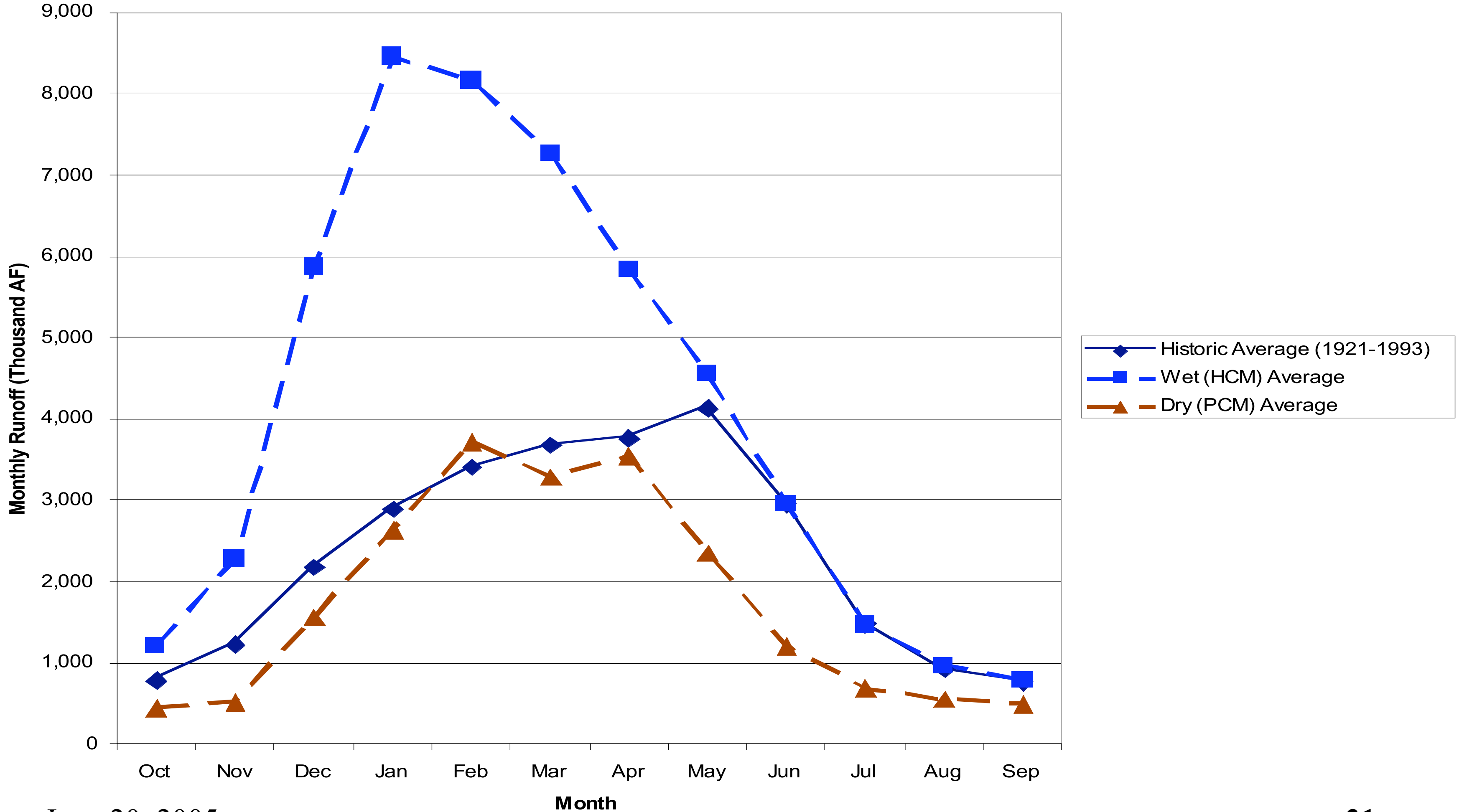
Analytic Approach

- Runoff scenarios were segmented by river basin, but have not yet been segmented by elevation so the importance in seasonal timing at different elevations can not yet be studied.
- This analysis identifies which river basins would be most affected.

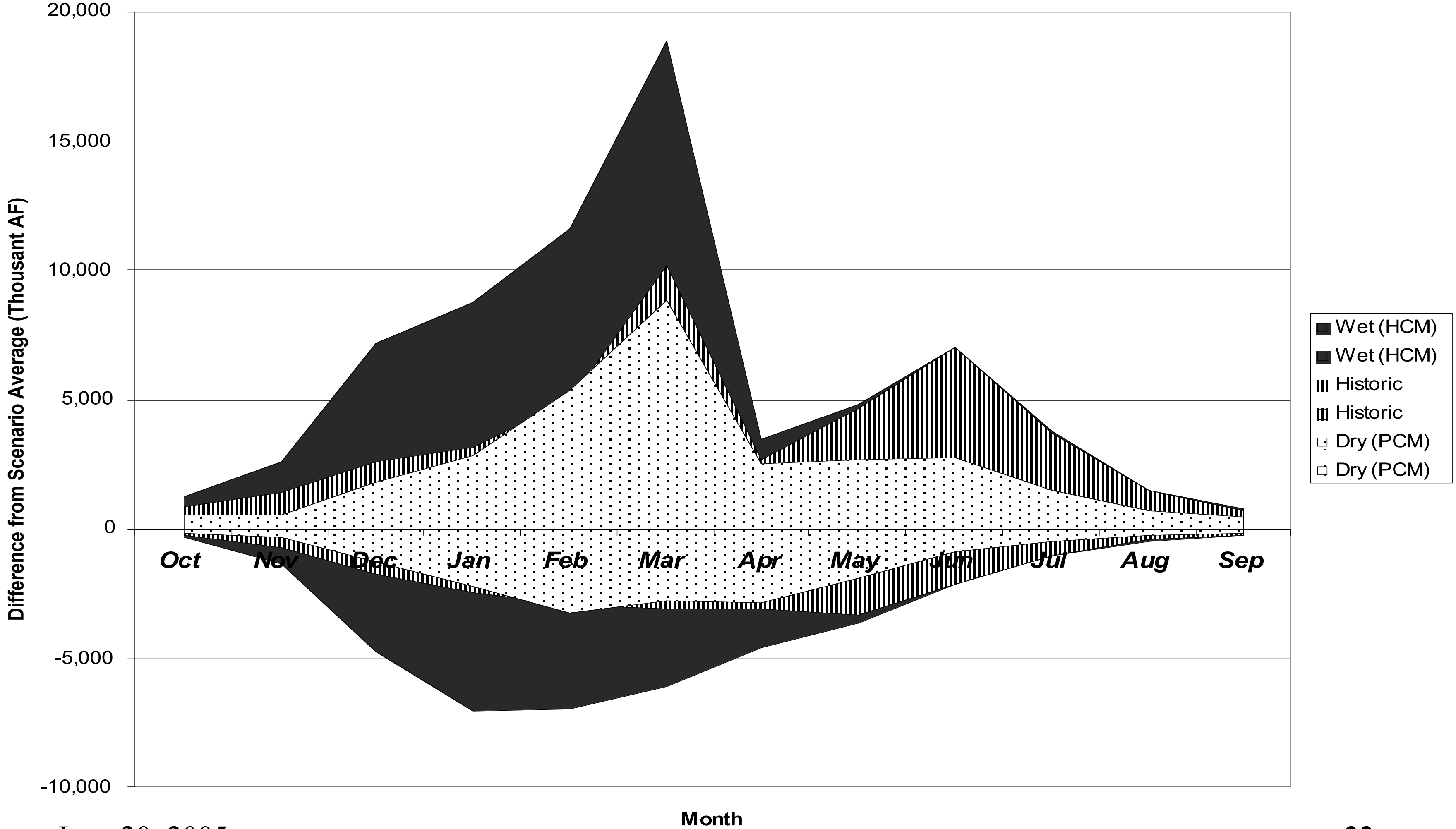
Figure 4-1 Comparison of Northern California Runoff Change for Year 2100 GCM Scenarios Wet (HCM) vs. Dry (PCM)



Comparison of Average Runoff for Historic, Wet (HCM) and Dry (PCM) Scenarios



Comparison of Range of Runoff for Historic, Wet (HCM) and Dry (PCM) Scenarios



Historic, Wet (HCM) and Dry (PCM) Scenarios

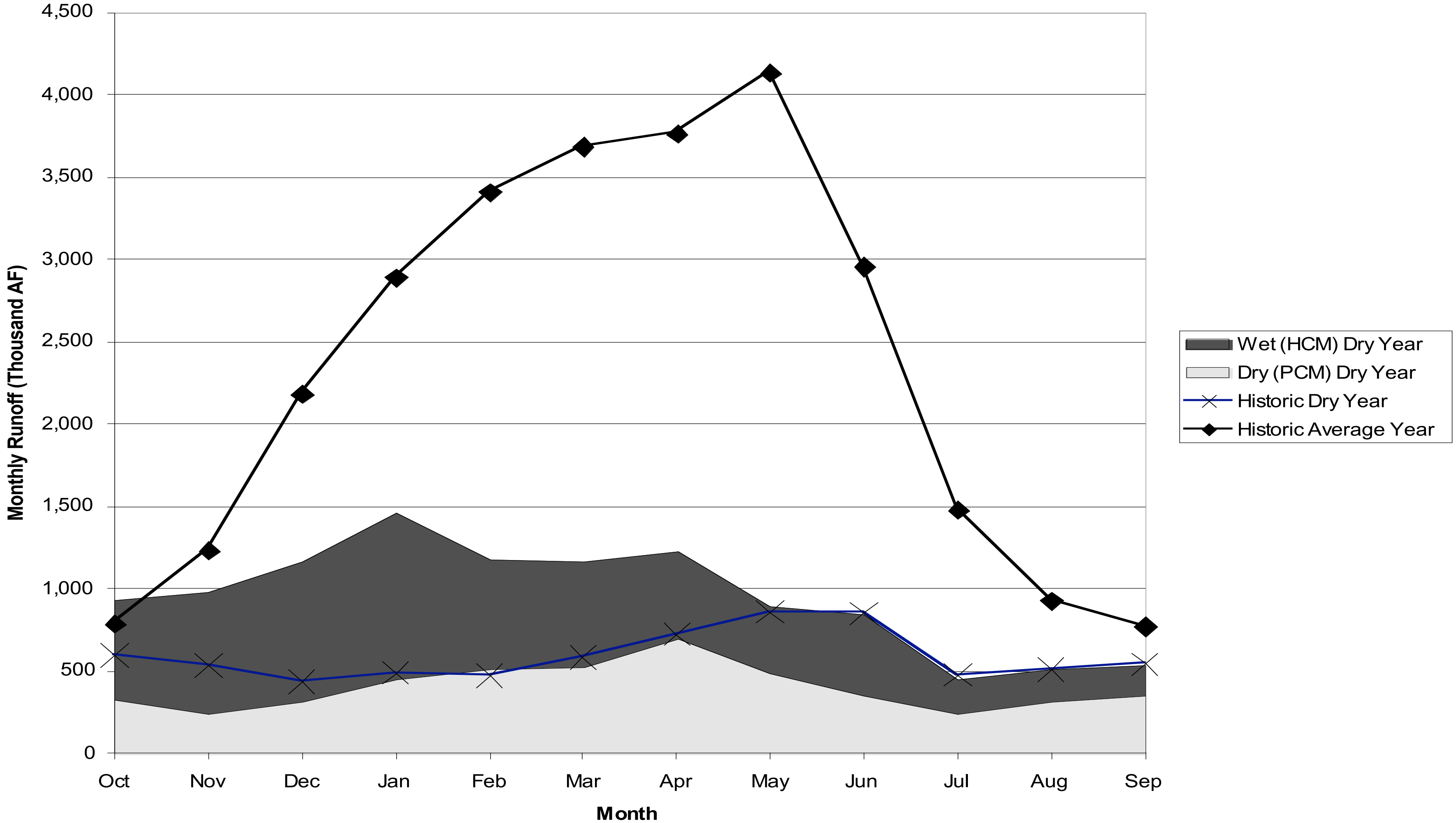


Figure 5-1 Usable Reservoir Capacity by Elevation Segments

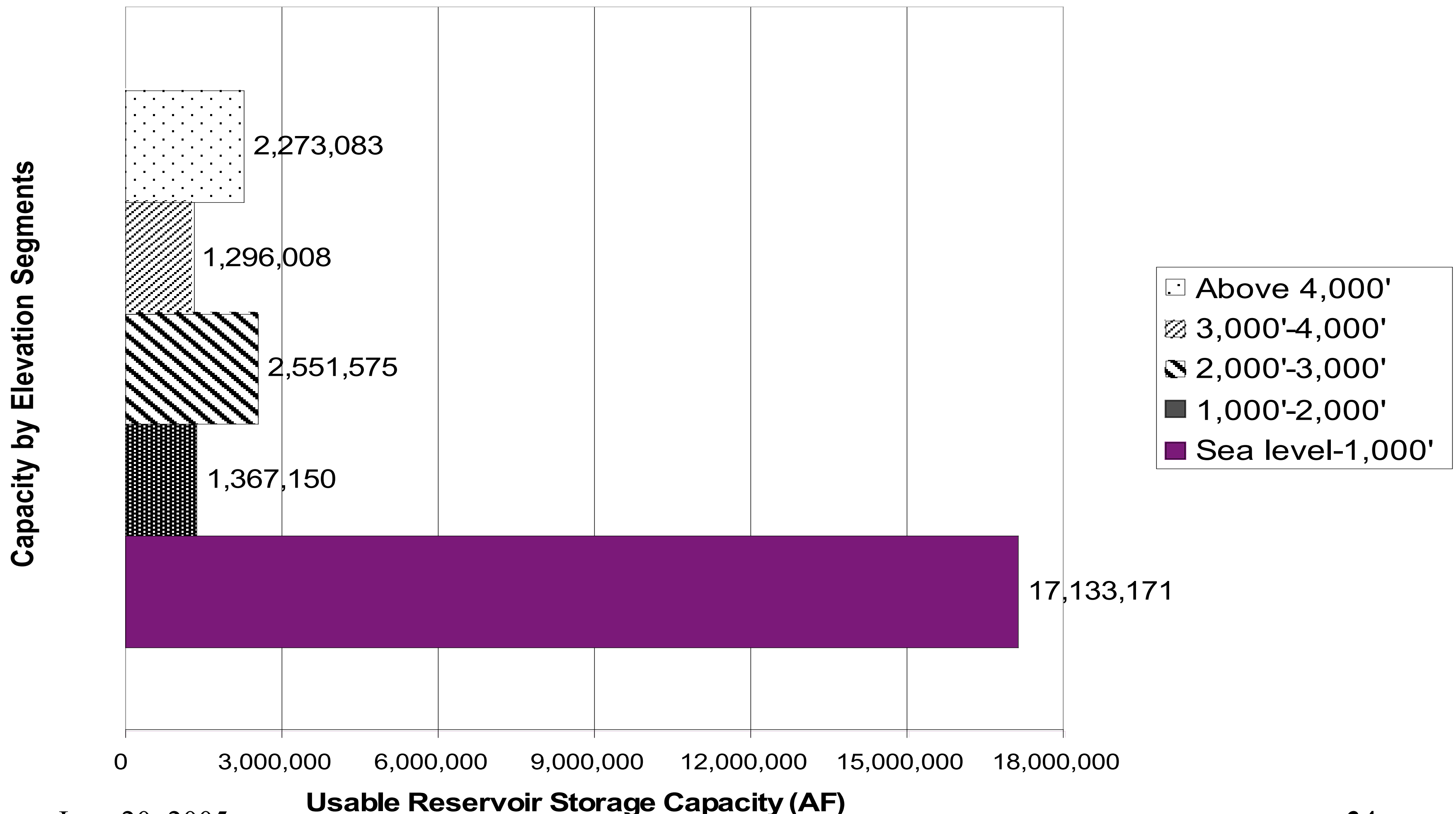


Figure 5-2 Dependable Hydro Capacity by Elevation Segments

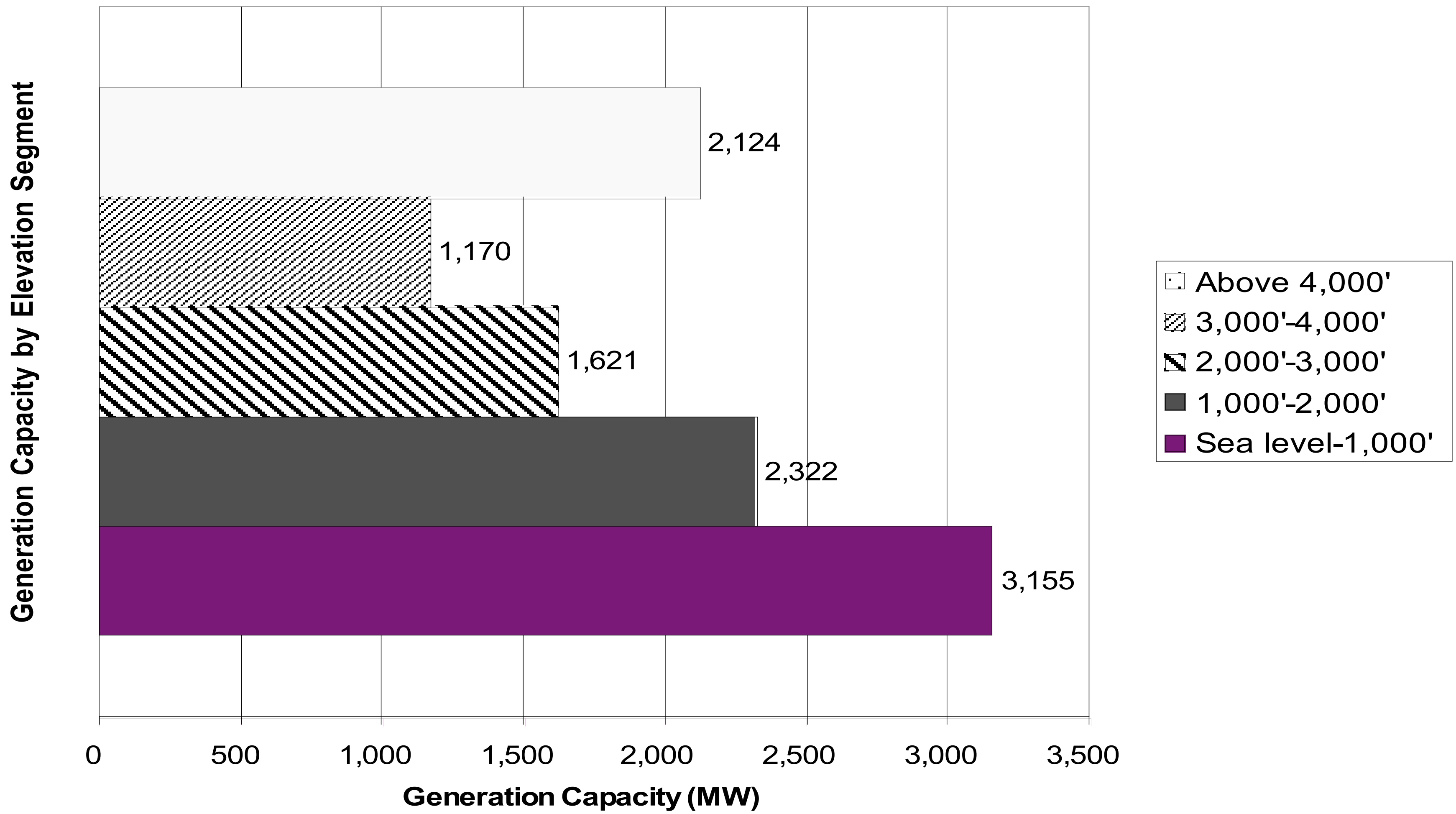


Figure 5-3 Average Annual Energy Production by Elevation Segments

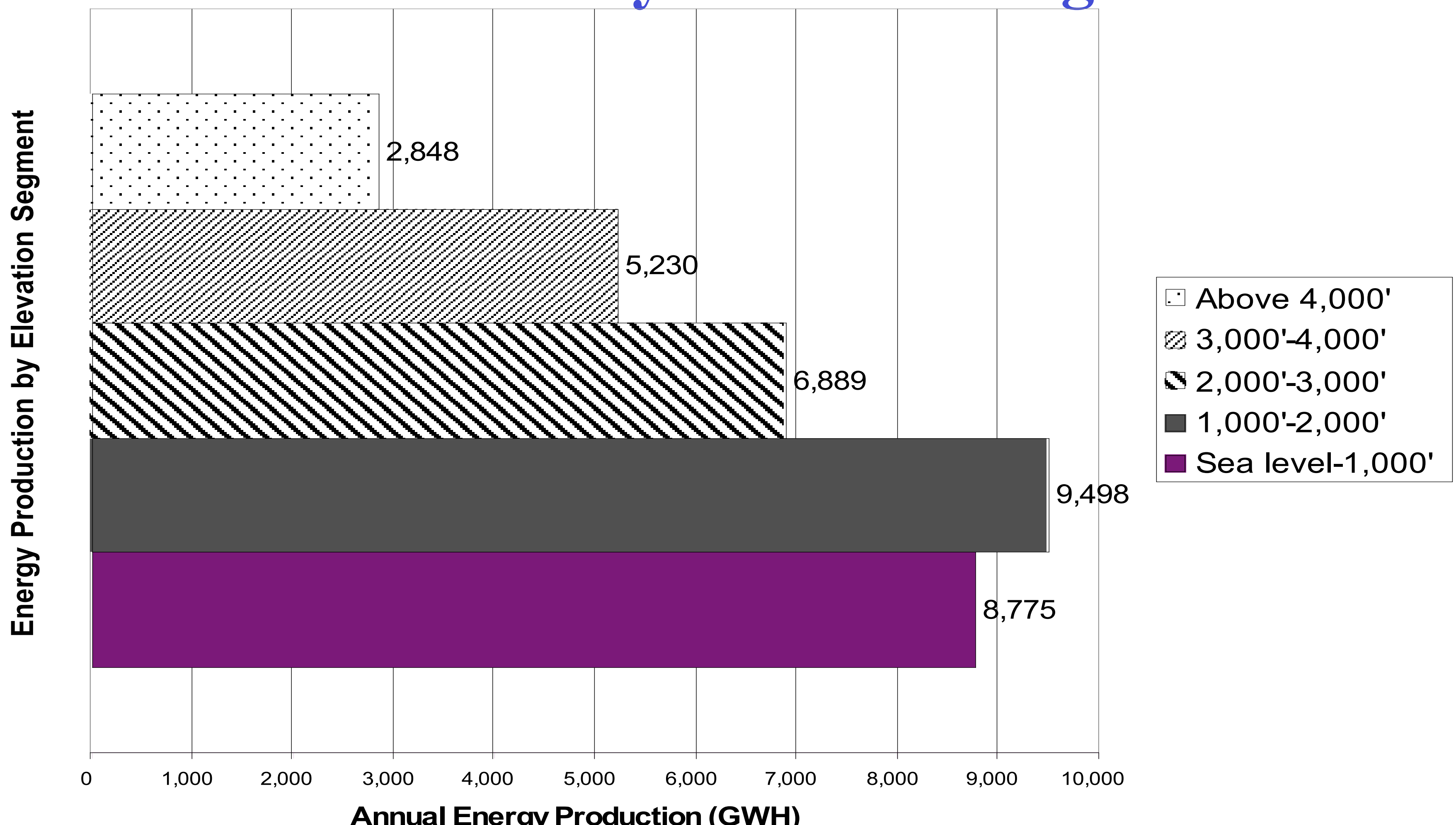


Figure 5-4 Energy Production per MW of Capacity by Elevation Segments

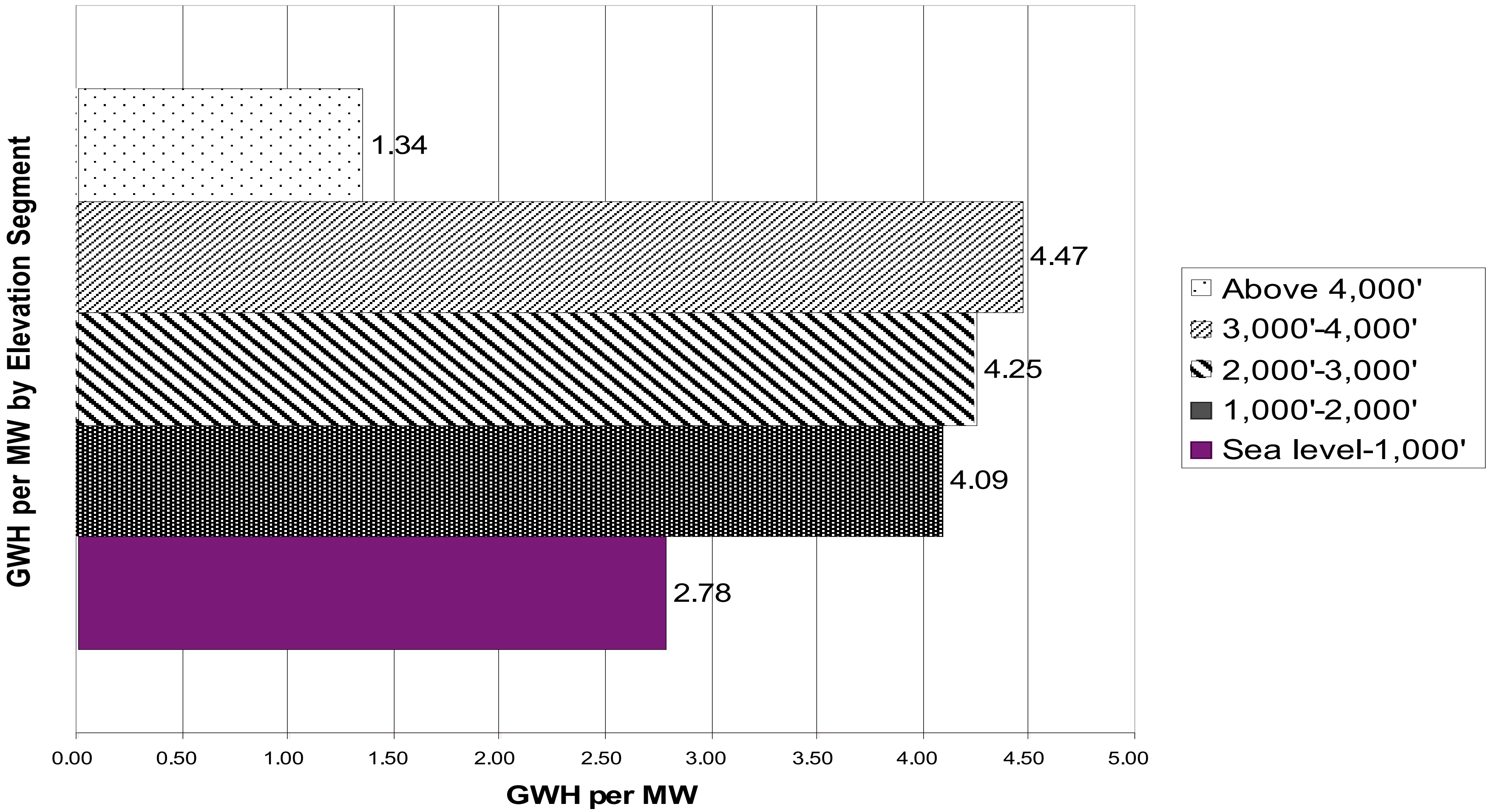


Figure 5-5 Comparison of Runoff Changes to Generation Capacity for Notable River Basins for Year 2100 GCM Scenarios: Wet (HCM) vs. Dry (PCM)

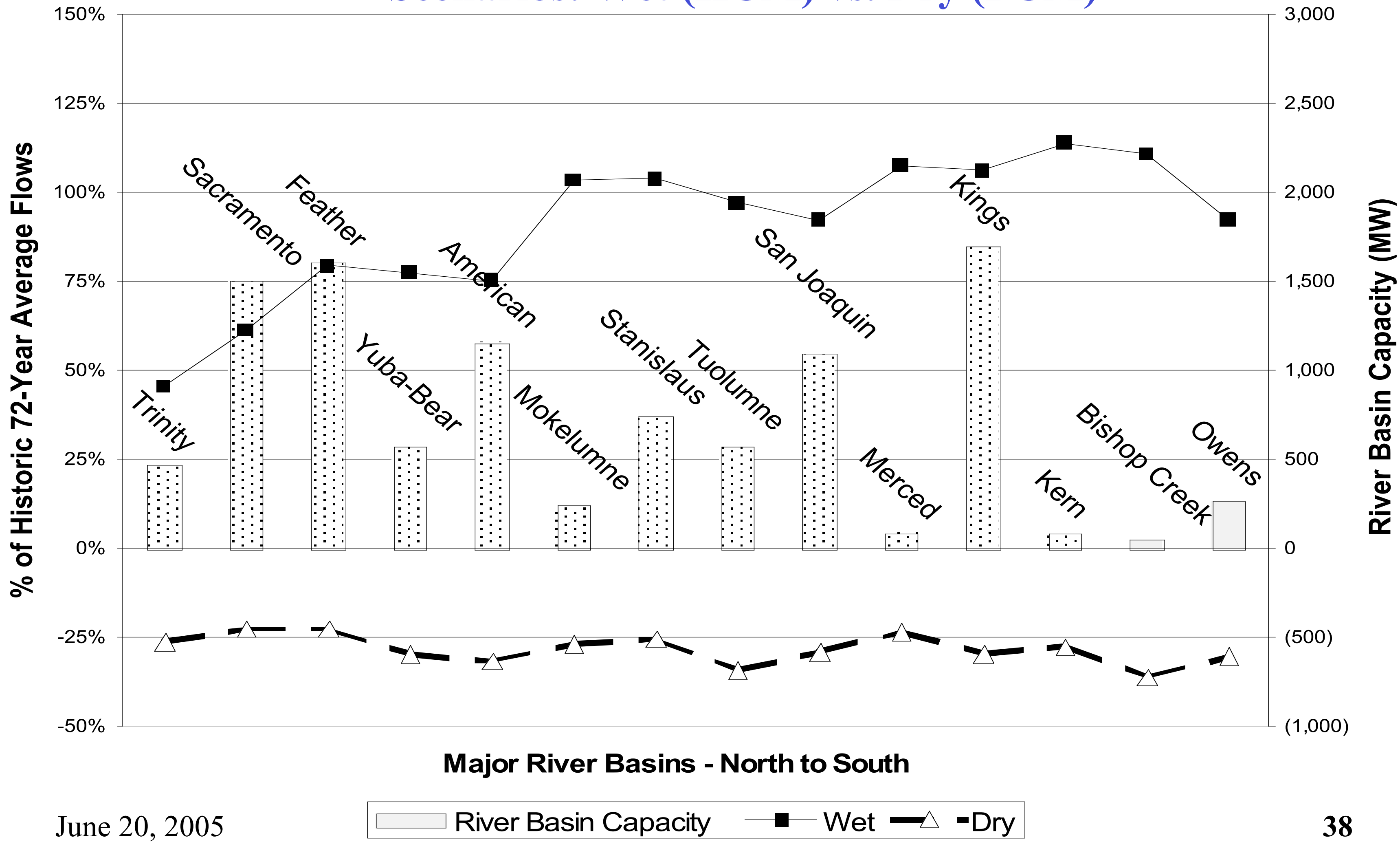
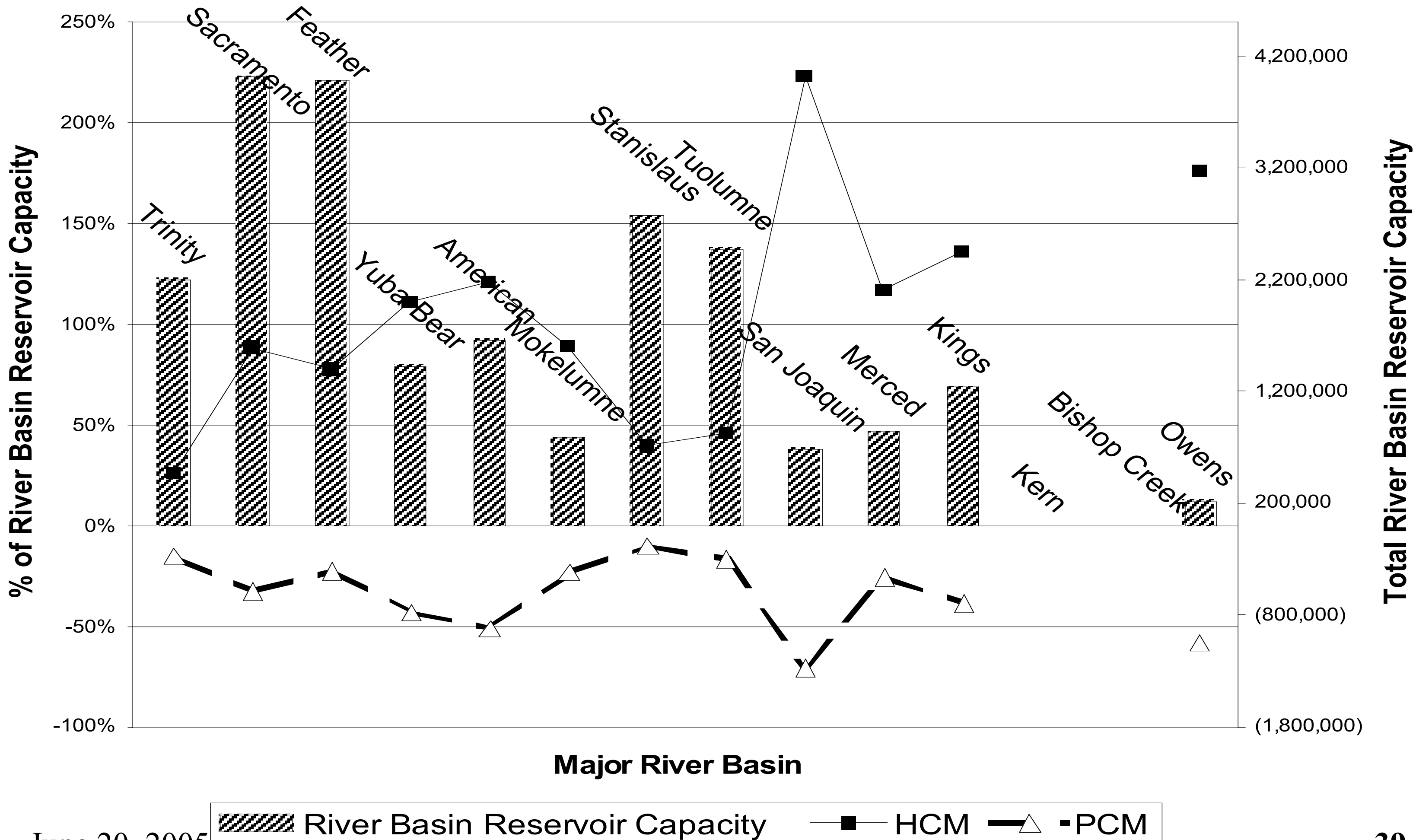


Figure 5-6 Comparison of Runoff Changes in Proportion to Reservoir Capacity for Notable River Basins for Year 2100 GCM Scenarios: Wet (HCM) vs. Dry (PCM)



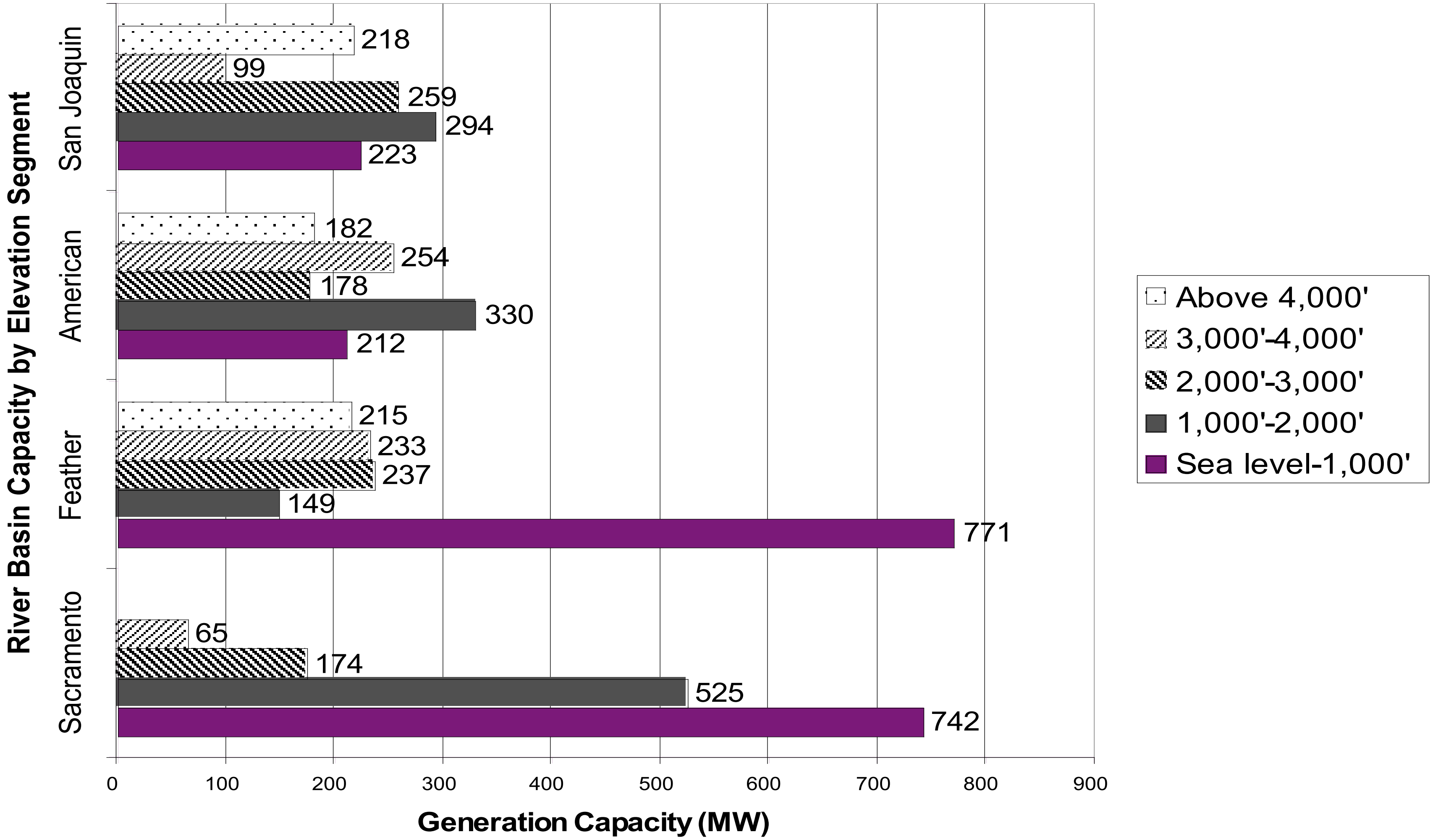
Selecting Important Basins for Future Focus

- Large amounts of generation capacity dependent on runoff
- Reservoir capacities small relative to potential changes in runoff
- Important to the state for specific reasons, e.g., Feather River for ancillary services
- Most affected by potential climate change

Four Basins to Monitor
"Canaries in a Coal Mine"

- Sacramento & Pit Rivers
- Feather River
- American River
- San Joaquin River

Figure 5-7 Dependable Hydro Capacity for Four Major River Basins by Elevation Segments



Summary of Findings

- A warming trend, no matter the cause, is evident in California
- Hydro is not a large resource in aggregate and will have diminishing importance statewide, yet it will continue to provide an important element of the state's summer peaking reserve capacity
- Hydro provides key services and is more important to specific municipal utilities
- Changes in the PNW will have a disproportionate affect on California resources

Findings Continued

- Purpose of water storage and hydro facilities are elevation dependent
- Generation capacity tends to be situated at higher elevations than water storage
- The snowpack is an important “reservoir” for peak season generation, and the hydro system is designed to take advantage of current snowmelt patterns
- Accelerated runoff in the spring will likely diminish hydro generation during the summer in any scenario, and create more pressure on flood control facilities
- Further study is needed on:
  - Changes in runoff at different elevations segmented by time of year
  - Changes in hydro output resulting from changes in runoff
  - Potential tradeoffs among hydro production, flood control, water supply and environmental services

Incorporating Climate Change in Hydro Operations and Planning

- Extensive Survey of California, Pacific Northwest, and Columbia River Basin
- Western U.S. – WECC, WIEB
- California – CEC, CAISO, CPUC, PG&E, SCE, SDG&E, DWR, USBR, ACE, LADWP, SFPUC, EBMUD, PCWA, MWD, MID
- PNW – NWPPC, BPA, Oregon, Washington, PacifiCorp, BC Hydro, USBR
- Colorado River Basin – USBR, NOAA

Results of Survey

- Most Planning and Operating Entities Tracking Studies
- Little Inclusion in Planning Documents; Uncertainty a Big Factor
- IOUs with Most Aggressive Program
- No Operational Changes Have Been Made
- States Far Ahead of Federal Government

Climate Change Impacts to Coastal Power Plants

- Climate Change May Cause Sea Level Rise, Increased Storm Intensity/Frequency
- Sea Level Rise Already Occurring (up to 8 in.)
- No Available Data on Sea Level Rise Effects on Coastal Plants
- Increase in Storm Intensity/Frequency Would Affect Diablo Canyon Power Plant